

SINGLE EVENT EFFECTS ON SPACE RADIATION HARDENED 64K SRAMS
AT ROOM TEMPERATURE*

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ABSTRACT

The laser threshold linear energy transfer for single event upsets can be estimated, even at room temperature, for space radiation hardened 64K SRAMs. The memories were independently developed to qualify for the Qualified Manufacturer's List by IBM and Honeywell. The memory was so hard that high energy heavy ions generated by the Van de Graaff could not determine the SEU threshold ($> 110 \text{ MeV-cm}^2/\text{mg}$) at room temperature. Use of pulsed laser tests would make it possible to forgo very expensive testing at ultra-high energy accelerators.

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SUMMARY

A. PURPOSE OF WORK

The purpose of these tests is to support microelectronic device quality assurance in the area of single event effects testing of the Advanced Spaceborne Computer Module (ASCM) for future space missions. Space radiation hardened 64K SRAMs (IBM6401CRH and HC6364) were independently developed by IBM and Honeywell under Government contract for ASCM, as an effort to be placed on the qualified manufacturer list (QML). Single event effects on these memories were tested with high energy heavy ions and picosecond pulsed dye lasers at JPL, as independent verification and validation for the Qualified Manufacturer List program of the Air Force Phillips Laboratory.

The IBM6401CRH is a 64K x 1, high speed (36 nsec/cycle at 25°C, $V_{DD} = 5V$), radiation hardened [total dose: 10^6 rads (Si), survivability: 10^7 rads (Si)/sec] CMOS SRAM. The memory features separate data I/O and fully asynchronous operation requiring no external clock. Address transition detectors initiate bit line pre-charging, resulting in improved performance. The device chip enable feature places the device in a low power (11 mW) standby mode reducing supply current to less than 2 mA. Device cells incorporate a six transistor CMOS design with polysilicon cross coupling resistors providing exceptional single event upset (SEU) hardness (10^{-10} fails/bit day). Nominal threshold LET of this device at 125°C based on IBM testing is 80 MeV-cm²/mg, but varies depending upon the cross-coupled resistor.

The HC6364 is an 8K x 8 radiation-hardened, high performance SRAM with industry-standard functionality. It is fabricated with the Honeywell radiation insensitive CMOS (RICMOS) technology, and designed for use in systems operating in space radiation environments. The SRAM operates over the full military temperature range, and requires only a single 5V power supply. Power consumption is typically 40mW/MHz in operation, and 5 μ W/MHz in the low power, disabled mode. The SRAM read operation is fully asynchronous, with an associated typical access time of 25 nsec. The Honeywell RICMOS technology employs advanced and proprietary design, layout, and process hardening techniques. It is a 5-volt, n-well, CMOS technology with a 259 angstrom gate oxide and minimum feature size of 1.2 μ m. Additional features include two layers of interconnect metalization, lightly doped drain structure for improved short channel reliability, and epitaxial starting material for latchup-free operation. High resistivity cross-coupled polysilicon resistors (150 - 700 K Ω) have been incorporated for single event upset hardening. The predicted threshold LET of this device at 125°C is approximately 40 MeV-cm²/mg depending upon the resistivity of the cross-coupled resistors.

A pulsed dye laser tests of both devices were also carried out as a technique for assessing SEU susceptibility of microelectronic circuits at a wafer level, a potential real time radiation hardness assurance for SEU, and a tool for understanding nodal upset sensitivity.

B. SIGNIFICANT RESULTS

Both devices were tested with high energy heavy ions at BNL. At room temperature, neither showed SEUs even at the upper limit of the accelerator. The highest energy heavy ions gener-

ated by the Van de Graaff in Brookhaven National Lab. were iodine (306 MeV) and gold (320 MeV). This means that the threshold linear energy transfer of the device should be higher than 110 MeV-cm²/mg. For IBM6401CRLI neither single event upsets nor latchups were observed even at the worst case conditions of 125°C.

Because of the exceptionally small device package, a similar size heating unit is needed for the high temperature tests, and the DUT test board socket geometry limits the beam angle of incidence to less than 45°. In these tests iodine (306 MeV, range of 32/tin) was used for covering LET from 56 to 79 MeV/mg/cm² at the total fluence of 10⁶ ions/cm² per run. A gold ion (320 MeV) was also used to verify the expected threshold LET (> 110 MeV-cm²/mg) of the device. All SEU tests were performed at V_{DD} = -4.5 V for the worst case, at normal high speed access/cycle of longer than 36 nsec. Six samples from different stages of the fabrication processes (beginning, middle, and end) were tested, two for the detailed LET curve and two for reproducing the observed threshold LET for each stage. All other test requirements followed the JPL's standard test procedures. Although device latchup was not expected, latch ups also were monitored at the initial test stage. The conditions are summarized in the Table 1.

Table 1. Test Conditions

1. V _{DD} (V)	4.5 -5.5 (only for latchup)
2. Temperature	R.T. - 125°C
3. Speed (riser)	20 - 45
4. Pattern	O's, 1's, and Checkerboard
5. Fluence (particles /cm ²)	10 ⁶
6. Flux (particles/cm ² - sec)	~ 10 ³
7. Ions	I ¹²⁷ (308 MeV) and Au ¹⁹⁷ (330 MeV)
8. Incident Angle	0-50 degree
9. LET (MeV-cm ² /mg)	60 -92.7 and 80-110
10. Range (μm)	30 -19 and 26 - 17

For the IIC6463 the threshold linear energy transfer was found to be approximately 50 MeV-cm²/mg at 125°C, depending upon their resistance of the cross-coupled resistors between the common gate and the sink. No latch ups were found, as expected, even for worst case conditions.

The pulsed dye laser can focus more energy into a specific ccl component than a cosmic ray. JPL, is one of the first to employ a picosecond pulsed dye laser with a bit mapping [1-2]. The bit mapper monitors whether specific memory cells are upset, as well as how many cells are upset by a single laser pulse. Upset cell addresses can also be directly related to a specific ccl element irradiated by a picosecond pulse. The system tunes the laser over a significant range of wavelength values (42511111-96011111). Because the silicon absorption coefficient varies

strongly with wavelength, the tunability and high-data-rate bit mapping allow one to determine an approximate depth profile of SEE sensitivity. The focused beam size ($1.5 \mu\text{m}$) is small enough to isolate a sensitive memory cell ($5 \mu\text{m} \times 10 \mu\text{m}$) on a chip. Because it combines the laser with computer image processing, the system provides the ability to locate the laser probe beam precisely at particular device locations, such as transistors. Wavelength and intensity selection allows determination of an effective laser energy transfer (LET).

When tested by a picosecond pulsed dye laser, numerous single event upsets were recorded for both 11046401 CR11 and 110463 memories, even at room temperature. This means that the pulsed laser beam can produce higher energy deposition than the Van de Graaff. Similar results were reported on non-rad hard SRAMs [3-4]. Analyses indicate that the threshold effective LET energies at room temperature are 109 for 11046401 CR11 and 106 MeV-cm²/mg for 1105401, respectively.

These study results clearly indicate that a simple test by pulsed lasers could be used for screening these highly radiation resistive space radiation hardened devices from different vendors even above the high energy upper limit of the cyclotron available at BNL without costly ultra-high energy tests.

C. IMPACT OF THE WORK

Space applications of microelectronic integrated circuits (ICs) are very attractive because they result in lower space craft power consumption and mass. However, IC reliability must be achieved prior to use in a space environment. Common concerns of IC quality assurance in space include cosmic radiation effects, such as single event upsets and latch ups, and other reliability requirements described in Military Standards.

It has been known for years that cosmic radiation in deep space can change the electrical properties of solid state devices, leading to possible system failure. In particular, high energy ionized particles, gamma rays, X-rays, and neutron bombardment have proven most harmful. Radiation hardened devices and circuits have been developed to minimize the impact of such effects. Proper design and processing techniques allow the microelectronic device to operate in this harsh space environment.

Electron-hole pairs generated in a memory cell node by cosmic rays can cause an upset (single event upset) of the data stored in the memory cell. The charge limit (critical charge) collected for the upset depends upon linear energy transfer (LET) from the incoming particles to the device material, effective sensitive volume, device topological layout, including cross-coupled resistors, and the carrier transport mechanism.

Correct prediction of device characteristics using a proper model to describe and simulate complicated physical and chemical effects in the device is challenging, but should be done for the successful future space missions. Individual devices should have a proven record of test data, such as threshold LET, numerical cross section, or effective critical charge collecting volume and typical SEU characteristics with respect to the device writing time.

The threshold laser energy transfer of the single event upsets on space radiation hardened 64K SRAM could be obtained at room temperature by a picosecond pulsed dye laser. The laser can cover the energy beyond the upper limit of the high energy heavy ions that the accelerator, Van de Graaff at BNL, can generate. This may mean save money and time to be able to define threshold LET by the laser testing without the expensive ultra-high energy testing in order to select the devices for space application.

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